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MOL
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PRELIMINARY DATA REPORT OF THE MOL PROTUBERANCE HEAT TRANSFER TEST (1AL1)

VOLUME I

MOL
MANNED ORBITING LABORATORY

5 FEBRUARY 1969 DAC 62731

PRELIMINARY DATA REPORT OF THE MOL PROTUBERANCE HEAT TRANSFER TEST (1AL1)
VOLUME I

Prepared under Contract Number F04695-67-C-0029
for MOL Systems Office,
Headquarters Space and Missile Systems Organization
Air Force Systems Command
United States Air Force

IN COMPLIANCE WITH THE REQUIREMENTS OF
EXHIBIT B, DATA ITEM NUMBER UT-132

By the MOL Subdivision
McDonnell Douglas Astronautics Company
Western Division
McDonnell Douglas Corporation
Huntington Beach, California

[redacted]

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PRELIMINARY DATA REPORT
OF THE MOL PROTUBERANCE
HEAT TRANSFER TEST (1AL1)

VOLUME 1

This report is MOL Data Item UT132

DAC No. 62731

February 1969

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INTRODUCTION

The MOL Protuberance Heating Test was conducted for the Air Force Space Systems Division under Contract Number F04695-67-C-0029. An outline of the Protuberance Heating Test was provided in a pre-test report, DAC 58780, dated 26 February 1968 (Reference 1).

The three phases of the test (boundary layer survey, flat plate in undisturbed flow, and protuberance/flat plate combinations) were successfully completed in that the objectives specified in the Fluid Dynamics Test Plan (Reference 2) were accomplished.

This report (Volumes 1 and 2) contains a presentation of the tabulated data obtained from the MOL Protuberance Heating Test and fulfills the requirements for data item UT-132. The report has been divided into two volumes in order to facilitate handling. Volume 1, DAC 62731, contains the primary text of the report. Volume 2, DAC 62732, contains the test data (shadowgraphs and printed data).

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ILLUSTRATIONS

1.0 INTRODUCTION

The MOL Protuberance Heating Test (1AL1) was conducted at the Douglas Aerophysics Laboratory (DAL) Four-Foot Trisonic Wind Tunnel between January and April 1968.

The test specimens consisted of one-half scale models of the thrustor module assembly, VVSA fairing, and equipment fairing. The models were mounted to the floor of the transonic cart; for these tests, the transonic cart served as a supersonic test section. The models and an instrumented section of the floor (consisting of forward, aft, and turntable segments) were constructed of 1/16 inch nominal thickness nickel material. The floor mounting was employed to obtain close simulation of the immersion of the flight articles in the vehicle boundary layer during boost. Testing was conducted between the Mach number range of 2.5 and 5.0. For all practical purposes, these Mach numbers bracket flight vehicle local Mach numbers during the period of maximum heating.

In March 1968 a model failure occurred when the forward and aft skin sections separated from the floor of the transonic cart and blew down the tunnel. The destroyed sections were later replaced with 3/8 inch aluminum plate instrumented with Nanmac thermocouple gages. A photograph of one of these gages is presented in Figure 20.

The remaining test runs were made with the aluminum floor sections; testing was completed on April 16, 1968.

A total of 114.4 wind tunnel hours were expended in accomplishing this test.

2.0 MODEL DESCRIPTION

Half-scale models of protuberances unique to the MOL vehicle were constructed and tested. These models included the thrustor module assembly, VVSA fairing, and equipment fairing. In addition to these protuberances, a thin floor skin was also constructed. These test items were constructed of 1/16 inch thick high purity nickel. The original floor skin consisted of a forward section, turntable, and aft section (Figures 3 and 4). The turntable contained provisions for mounting the protuberances and for yawing the models to as much as $\pm 24°$. Only the thrustor module assembly and thrustor module assembly-VVSA fairing combination were yawed. Approximate dimensions of the models are included in Figures 8 through 16. Photographs of the models installed in the tunnel are shown in Figures 5 through 7.

Subsequent to failure of the floor skin (Figures 17 and 18), the forward and aft skin sections were replaced with 3/8 inch thick aluminum plates as shown in Figure 19. Instrumentation locations on these plates were essentially the same as on the original skin.

The model construction incorporated a precooling system wherein LN_2 was circulated through the models prior to each run. This lowered the temperature of the models and insured a more pronounced response from the thermal instrumentation to surface heating. The cooling tubes and associated insulation of the floor skin are shown in Figures 1 and 2. A hydraulically actuated shoe protected the model and floor skin instrumentation during the tunnel start.

3.0 DATA DESCRIPTION

3.1 Shadowgraphs

Shadowgraphs were obtained by mounting a 35 mm camera and a light source on one side wall of the test section and painting the opposite wall white. Photographs were taken of the shock patterns which were projected on the wall during runs with the protuberances installed. Because of the nature of the physical setup, some distortion is in evidence. All available shadowgraphs are provided in the data section of this report. Each photograph is identified by a run number; the corresponding tunnel flow conditions for specific runs may be obtained from Table 1.

The variation noted in some cases between the identifying run number and that painted on the side wall resulted when consecutive runs were made without opening the tunnel to re-paint the numbers. Shadowgraphs of the shock system generated by the forebody of the equipment fairing were not obtained because of a malfunction in the camera system during these runs.

3.2 Tabulated Data

The tabulated data resulting from all three phases of the test are provided in Volume II. The data are identifiable by the run number printed in the upper right-hand corner of each page. Tabulated output consisted of tunnel freestream parameters plus heat transfer and pressure data for each good run. A summary of acceptable runs is provided in Table 1.

The tabulated data are preceeded by a key (Table o) which provides a description of the pertinent tabular headings for each set of tabular output. In addition to tabulated pressure and heat transfer data, the printed data from the boundary layer runs have also been included.

In order to assess the relative value of the printed data, specific comments for certain runs have been provided.

3.2.1 General Comments on Tabulated Data

The copper constantan thermocouple temperature time histories were curve fitted in two ways. Data point 1 values are the result of curve fitting 31 consecutive measurements immediately after shoe retraction. These data should match exactly the as-run data, for most runs.

3.2.1 General Comments on Tabulated Data (cont.)

Under data point 2, the copper constantan thermocouple outputs were curve fitted by skipping the first 14 consecutive measurements, then curve fitting every other measurement out of the next 62. If sufficient readings were not available, point 2 was not printed out.

The NANMAC thermocouple output was curve fitted over the first 21 consecutive readings immediately following shoe retraction (NANMACS are confined to those heat transfer data labeled FS and AS subsequent to run 74). The point 2 data for the NANMACS are invalid.

Data points numbered three or greater should be disregarded in all cases. Scanivalve hookup sheets are provided in Table 5 to aid the user in identifying which model pressures were compromised by a diminishing $P_{t\infty}$ and loss of flow. If a pressure is flagged in the tab data, it indicates that the pressure did not stabilize.

The pressure ratio P/PS will suffer reduced accuracy if it happened that tunnel total pressure was dropping at the time a particular model pressure was read, even though flow might still be supersonic. The reason for this is that a PS (PSIA) was stored by the program early in the run. A more accurate P/PS can be hand calculated by referring to the scanivalve port number that corresponded to the model pressure of interest.

On the first page of the pressure data for each run are listed a group of pressures labelled PR1, PR2, etc. These represent the several ports on each module (channel) of the scanivalves that were connected to a reference pressure. The reference pressure was also read by a separate transducer, and the reading is labelled PREF. When large discrepancies appear between PREF and PRX, model pressures connected to the same channel as the erroneous PRX should be seriously questioned. Usually, discrepancies appear when PREF is much higher than the model pressures, resulting in a pressure lag problem. A majority of the pressure taps were connected to 10 PSIA transducers; therefore, pressures of 10.2, 10.8, etc. may indicate that a transducer is pegged. This condition could result from a transducer or tap either being open to the atmosphere or responding to a high local model pressure. The data have not been reviewed in detail to differentiate between these two conditions. In addition, a small number of transducers used had a range to 15 PSIA.

Table 1 provides a complete summary of runs for which data were provided. All run numbers which are not mentioned in Table 1 were not acceptable, with the exception of runs 72 and 147. At the time this report was readied for print,

3.2.1 General Comments on Tabulated Data (cont.)

the test facility was experiencing difficulty in reducing these runs, and it was not known if the data quality would permit an acceptable reduction. In addition, some re-reduction is necessary for runs 62, 96, 138, 139, and 143, although uncorrected data are provided for those runs in this report. In the event all or part of these data eventually becomes available it will be published as an addendum to this report.

In general, the printed data are satisfactory as received; however, there are small deficiencies in the data on certain individual runs. As a result, specific comments regarding these deficiencies have been included as an aid to the user of the data.

.2.2 Specific Comments on Tabulated Data

Run 61

Lost ports 9-13. Lost flow. See scanivalve hookup sheet to identify resulting lost pressures.

Starting with port 7, $P_{t\infty}$ and P_{∞} [PS (PSIA)] were dropping off during the time model pressure data were being taken, so the P/PS column will be in error.

Run 62

The point 2 heat transfer data could not be reduced properly and the reason was not discovered.

Run 65

Lost flow at port 13.

$P_{t\infty}$ dropping off at port 12.

Run 66

Lost tunnel flow at port 13.

$P_{t\infty}$ dropping off at port 12.

Run 67

Tunnel flow lost at port 11.

$P_{t\infty}$ dropping off at port 10.

Run 72

Reduced data not available due to reduction difficulty.

Run 74

The model failure occurred during this run. Consequently no acceptable data were recorded. For all succeeding runs, the forward and aft floor plates were

Run 74 (cont.)

instrumented with NANMAC Chromel-Alumel thermocouples. The only valid heat transfer data are point 1 values in the reduced data for the NANMACS.

Run 76

The heat transfer data are badly scattered, apparently because of inadequate precooling and noise. The reference pressure was very high in comparison to P_∞, so some pressure readings were invalidated, due to lag time. Reference pressures were misread.

Run 77

The heat transfer data are badly scattered, apparently because of inadequate precooling and noise. The reference pressure was very high in comparison to P_∞,so some pressure readings were invalidated. Reference pressures were misread.

Run 80

During this run, the signal from many transducers shifted to the channel adjacent to the correct one (e.g., data correctly listed on channel 50 shifted to channel 49). This happened at the time of shoe retraction.

In order to save these data, a tunnel total temperature was estimated from raw data counts and dubbed into the program. This corrected the adiabatic wall temperature. The labels on the tabulated data (FS, AS, TS numbers) were then changed by hand in the reduced data. The point 1 data only are marked up, but succeeding temperature data points require the same correction.

The channel shift problem did not affect the model pressure data or $P_{t\infty}$ (it is not known why $P_{t\infty}$ did not print correctly in the heat transfer section of the data). Flow was lost at port 9 and certain model pressures were affected by the high reference pressure, introducing the lag problem. Pressure data for runs 85 to 87 are considered superior (runs 80, 82, and 85 to 87 were all run at the same freestream conditions).

Run 82

Same as comments for #80, except flow was lost at port 7 and $P_{t\infty}$ started falling off at port 6.

Run 84

There was no cooling on the forward plate for runs 84-146, in order to better utilize the available liquid nitrogen. Consequently, any forward skin temperature data for these runs are invalid.

Special 100 H_z filters were used with the NANMACS starting with run 84 in an attempt to eliminate noise in the data and diminish the scatter in the heat transfer coefficient.

Indications are that starting with run 84, pressure tap AS 1 opened up to the atmosphere and was consequently invalid for the balance of the test.

Runs 85-87

There was little or no precooling before these runs, so all heat transfer data are invalid.

An attempt was being made during these runs to raise $T_{t\infty}$ to insure that there was no air liquifaction present. In this respect, run 87 had the highest $T_{t\infty}$ and is therefore superior.

The accuracy of the model pressure data was undoubtedly affected by the high reference pressure. The scatter in the data is also a function of the difficulty in measuring such low pressures.

Run 88

It is fairly obvious from the heat transfer data that T 44 and T 51 are invalid. Note that on run 90 they are all right. These thermocouples were all connected to the same amplifier, and a characteristic of this setup is that if one thermocouple generates or picks up excessive noise, all thermocouples on that channel may also be affected.

Thermocouples located on the various thrustor nozzles were not precooled, so the data from these are generally inferior.

Run 90

Flow maintained throughout run, but $P_{t\infty}$ dropping off starting with port 14, so P/P_∞ data for pressure taps on ports 14 and 15 will be in error.

Run 91

Thermocouples T 44 and T 51 again no good for reason given in comments for run 88. Port 15 was lost, and $P_{t\infty}$ was falling off for ports 13-15.

Run 92

Thermocouples T 44 to T 51 no good for reason given in comments for run 88. Flow

Run 92 (cont.)

was lost for ports 13-15, and $P_{t\infty}$ was falling off at port 10.

Run 93

Thermocouples T 44 to T 51 may or may not be good for reason given in comments for run 88.

Flow was lost for port 15, and $P_{t\infty}$ was falling off ports 12-15.

Run 94

$P_{t\infty}$ falling off ports 13-15.

Run 95

Lost flow ports 12-15. $P_{t\infty}$ dropping off ports 11-15.

Run 96

$P_{t\infty}$ dropping at port 15. The value of h_o is incorrect (should be 0.0065). Corrected reduced data were not available.

Run 98

T 44 and T 51 no good for reason provided in comments for run 88.

Run 99

T 44 to T 51 no good for reason provided in comments for run 88.

Run 101

T 44 to T 51 may or may not be good for reason provided in comments for run 88. Lost ports 7-15. $P_{t\infty}$ dropping off ports 6-15.

Run 102

The model was not precooled for this run, in order to obtain a complete set of pressure data.

The problem of the reference pressure introducing lag errors apparently recurred during this run. Also a problem here was the difficulty of measuring such low pressures.

Run 103

For runs 103 to 124, T 61 is a dummy.

TS53 and TS54 are both duplicated in runs 103 to 124. The data listed for these are correct (i.e., the duplication does not indicate that some thermocouples are mislabled in the data).

Thermocouples T 44 to T 51 are no good for reasons provided in the comments for run 88. Lost ports 17-18. $P_{t\infty}$ dropping ports 16-18.

Run 104

Thermocouples T 44 to T 51 are no good for reasons provided in comments for run 88.

$P_{t\infty}$ dropping for ports 17-18.

Run 105

T 44 to T 51 are no good for reasons provided in comments for run 88.

Many of the model pressures for this run are bad, because the reference pressures were misread. It is suggested that run 135 be used for P_{∞} data.

Ports 17-18 were lost. $P_{t\infty}$ was dropping off ports 15-18.

Run 106

T 44 to T 51 are no good for reasons provided in comments for run 88.

Lost ports 16-18. $P_{t\infty}$ dropping ports 14-18.

Run 107

Lost ports 14-18. $P_{t\infty}$ dropping ports 13-18.

Run 108

Lost ports 17-18. Thermocouples T 44 to T 51 no good for reason provided in comments for run 88.

Run 114

Thermocouples T 44 to T 51 may or may not be good for reason provided in comments for run 88.

Run 115

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88.

Lost ports 13-18. $P_{t\infty}$ dropping off ports 12-18.

Run 119

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88.

$P_{t\infty}$ dropping off port 18.

Run 120

Pressure data no good.

Run 121

Temperature data inferior. Model was not precooled.

Lost ports 17-18. $P_{t\infty}$ dropping off ports 15-18.

Run 122

Thermocouples T 44 to T 51 no good for reason provided in comments for run 88.

Run 122 (cont.)

Lost ports 8-18. $P_{t\infty}$ dropping off ports 6-18.

Run 123

Temperature data inferior. Model was not precooled.

Run 124

Temperature data inferior. Model was not precooled.

Run 125

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88.

Run 126

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88.

Lost ports 6-18. $P_{t\infty}$ falling off ports 5-18.

Run 127

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88. All pressure data are invalid because tunnel flow was lost.

Run 128

Temperature data will be inferior. Model was not precooled.

$P_{t\infty}$ falling off ports 17-18.

Run 129

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88.

Run 130

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88.

Run 132

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88.

Run 135

Lost ports 17-18. $P_{t\infty}$ dropping off ports 16-18.

Run 136

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88.

Lost ports 13-18. $P_{t\infty}$ dropping off ports 11-18.

Run 137

Thermocouples T 44 to T 51 no good for reasons provided in comments for run 88.

Lost ports 16-18. $P_{t\infty}$ dropping off ports 14-18.

Run 138

h_o for this run should be .0055. Corrected reduced data had not been received from the test facility at the time this report was printed.

Lost ports 13-18. $P_{t\infty}$ falling off ports 13-18.

Run 139

h_o for this run should be 0.0055. Corrected reduced data had not been received from the test facility at the time this report was printed.

Thermocouples T 44 and T 51 no good for reasons provided in comments for run 88.

The temperature data for this run are inferior because the model was not precooled.

Lost ports 15-18. $P_{t\infty}$ was falling off ports 14-18.

Run 140

Lost ports 14-18.

The second group of reference pressures (PR11, PR12, PR20) were badly misread by the second scanivalve. All pressures on the second scanivalve (refer to scanivalve hookup sheet) should be considered invalid.

Run 141

Run 141 was the first run with the equipment fairing. For runs 141 to 146, the forward skin thermocouples (FS) were not cooled, so data for these are invalid.

Run 143

The $P_{t\infty}$ print out of run 143 is wrong, so the pressure ratios are incorrect. The heat transfer data are all right.

A corrected reduction had not been received from the test facility at the time this report was printed.

Run 147

For runs 147 to 153, the aft skin (AS) thermocouples were not precooled so they are not printed out. In addition, all forward and aft skin pressure taps were connected to read only the reference pressure, not model pressures.

Run 147 was not provided because of difficulty in reducing the data.

Run 151

Lost ports 7-9.

Run 152

The second scanivalve badly misread all reference pressures, so all pressures on this scanivalve should be considered bad data.

4.0 TEST SUMMARY

The protuberance heating wind tunnel test was conducted for the purpose of determining heating rates and static pressure distributions on and around various protuberances mounted external to the MOL vehicle skin. The protuberances used in this investigation were half-scale models of actual protuberance configurations on the MOL vehicle. Liquid nitrogen was circulated beneath the instrumented floor section and through the models prior to each run in order to augment thermal response of the system. A hydraulically actuated shoe system protected the models and instrumentation prior to each test run. This shoe was retracted after fully developed flow was attained in the test section during each run.

The forward and aft skin sections separated from the floor during run 74 and were subsequently destroyed. Testing continued after replacing these two sections with thick aluminum plate. The thermal instrumentation in this area was replaced with individual NANMAC thermocouple gages and the pressure instrumentation consisted of the same complement of taps originally specified.

Data were taken during the test using a multiblock mode, which made it possible to monitor a maximum of 192 data channels during each run. Data gathering was initiated just prior to shoe retraction in each case; temperature data were recorded first, followed by a scanning of the pressure ports. The amount of time alotted for each data gathering sequence was varied from run to run and was governed primarily by available tunnel run time.

The error in the pressure data is estimated at $\pm.026$ psi for P, regardless of pressure level. For P/P_∞, the error is estimated at $\pm3\%$ for Mach 2.5 to $\pm25\%$ at Mach 5.0; these errors are estimated for ratios of P/P_∞ on the order of 1.0 or greater. The accuracy quoted for pressures is approximately $\pm0.5\%$ of full scale transducer readings, so the pressure data appear to be of good quality. The accuracy of the heat transfer data is estimated to be $\pm33\%$ and is below state-of-the-art quality if state-of-the-art is taken to be $\pm20\%$. This error range is applicable to both the thermocouple and the NANMAC gage instrumentation. In the case of the thermocouples, the major contribution to the uncertainty is the slope, dT/dt, obtained from different curve fits. The difficulty arises from the low signal-to-noise ratio which existed during this test. In the case of the NANMAC gages, the slope is again the major uncertainty. It should be noted, however, that for the NANMACS the slope is not a linear function.

4.0 Test Summary (cont.)

These quoted accuracies are based on a random error analysis of the instrumentation and recording system and do not include possible errors due either to moisture on the surface of the model skin or to large gradients on the surface from one thermocouple location to another. Measurements taken under unusual conditions, such as a pressure obtained when $P_{t\infty}$ was unstable, obviously may be outside the quoted accuracy range.

TABLE 1

RUN SUMMARY

Phase I

CONFIGURATION	Run Number	Nominal Mach No.	$P_{t\infty}$ (Psia)	Shadowgraph	Yaw Angle β (Deg)
Boundary Layer Rakes	35	2.5	27		
	40	3.0	40		
	41	3.0	30		
	43	3.5	65		
	44	3.5	40		
	45	4.0	95		
	46	4.5	110		
	60	5.0	110		
Phase II					
Flat Plate	61	3.5	65		
	62	3.5	65		
	63	3.5	40		
	65	3.0	40		
	66	3.0	35		
	67	2.5	27		
	68	2.5	27		
	69	4.0	95		
	76	4.5	85		
	77	4.5	110		
	80	5.0	110		
	82	5.0	115		
	84	3.5	65		
	85	5.0	110		
	86	5.0	115		
	87	5.0	110		
Phase III					
Thrustor	88	3.5	65	X	0
	90	3.5	65	X	+12
	91	3.5	65	X	-12
	92	4.0	95	X	-12
	93	4.0	95	X	+12
	94	4.0	95		0
	95	3.0	40	X	0
	96	2.5	27	X	0
	97	4.5	85	X	0
	98	4.5	85	X	+24
	99	4.5	85	X	-24
	100	4.5	85	X	-24
	101	5.0	115	X	0
	102	5.0	115	X	0

TABLE 1 (cont.)

RUN SUMMARY

CONFIGURATION	Run Number	Nominal Mach No.	$P_{t\infty}$ (Psia)	Shadowgraph	Yaw Angle β (Deg)
Thrustor & VVSA Fairing	103	3.5	65	X	0
	104	3.5	65	X	+12
	105	3.5	65	X	-12
	106	3.5	65	X	-12
	107	3.0	40	X	0
	108	2.5	27	X	0
	109	4.0	95		0
	110	4.0	95	X	+12
	111	4.0	95	X	+12
	112	4.0	95	X	-12
	113	4.5	85	X	0
	114	4.5	85	X	+24
	115	4.5	85	X	+24
	119	4.5	85	X	-24
	120	5.0	115	X	-24
	121	5.0	115		-24
	122	5.0	115	X	+24
	123	5.0	115	X	+24
	124	5.0	115		0
	125	5.0	115	X	0
	126	5.0	115	X	+24
	127	5.0	115	X	-24
	128	5.0	115	X	-24
	129	4.5	85		-24
	130	4.5	85		+24
	131	4.5	85	X	0
	132	4.0	95	X	0
	133	4.0	95	X	+12
	134	4.0	95	X	-12
	135	3.5	65	X	-12
	136	3.5	65	X	+12
	137	3.5	65	X	0
	138	3.0	40	X	0
	139	3.0	40		0
	140	2.5	27	X	0
Equipment Fairing	141	2.5	27		
	142	3.0	35		
	143	3.5	40		
	144	4.0	95		
	145	5.0	110		

TABLE 1 (cont.)

RUN SUMMARY

CONFIGURATION	Run Number	Nominal Mach No.	P_{t_∞} (Psia)	Shadowgraph	Yaw Angle β (deg)
Equipment Fairing (cont.)	146	4.5	115		
	148	4.0	95		
	149	3.5	40		
	150	3.0	35		
	151	2.5	27		
	152	3.0	35		
	153	5.0	110		

TABLE 2

INSTRUMENTATION LOCATIONS FOR FORWARD FLOOR SKIN

THERMOCOUPLES

T. C. No.	X	Y	T. C. No.	X	Y
1	15.000	+18.000	15	21.750	+6.00
2	23.000	+14.000	16	35.000	+2.000
3	21.000	↓	17	33.000	↓
4	19.000	↓	18	31.000	↓
5	31.000	+ 8.000	19	29.000	↓
6	29.000	↓	20	27.000	↓
7	27.000	↓	21	37.000	0.000
8	25.000	↓	22	35.000	↓
9	23.000	↓	23	33.000	↓
10	21.250	↓	24	31.500	↓
11	29.000	+6.000	25	33.000	-2.000
12	27.000	↓	26	31.000	↓
13	25.000	↓	27	29.000	↓
14	23.000	↓			

PRESSURE TAPS

P. T. No.	X	Y	P. T. No.	X	Y
1	33.000	+6.000	4	27.000	-2.000
2	31.000	↓	5	23.000	↓
3	35.000	-2.000	6	15.000	-18.000

TABLE 2 (cont.)

INSTRUMENTATION LOCATIONS FOR FORWARD FLOOR SKIN

NOMINAL DIMENSIONS

Runs 75-87

THERMOCOUPLES

T. C. No.	X	Y	T. C. No.	X	Y
1	15.000	+18.000	15	21.750	6.000
2	21.000	16.500	16	35.000	+2.000
3	21.000	14.000	17	33.000	
4	19.000	14.000	18	31.000	
5	31.000	8.000	19	29.000	
6	29.000		20	27.500	
7	27.000		21	37.000	0.000
8	25.000		22	35.000	
			23	33.000	
10	21.250		24	31.500	
11	29.000	+ 6.000	25	33.000	-2.000
12	27.000		26	31.000	
13	25.000		27	29.000	

PRESSURE TAPS

P. T. No.	X	Y	P. T. No.	X	Y
1	33.000	6.000	4	27.000	-4.000
2	31.000		5	25.500	-6.000
3	35.000	-2.000	6	15.000	-18.000

TABLE 3

INSTRUMENTATION LOCATIONS FOR TURNTABLE SKIN

THERMOCOUPLES

T. C. No.	X	Y	T. C. No.	X	Y	T. C. No.	X	Y
1	-11.000	+16.000	19	-5.000	+12.000	37	+3.000	+10.000
2	- 1.000		20	-3.000		38	+5.000	
3	+ 1.000		21	-1.000		39	+9.000	
4	+ 3.000		22	+1.000		40	+11.000	
5	-12.500	+14.000	23	+3.000		41	+15.000	
6	-11.000		24	+5.000		42	-17.000	+ 8.000
7	- 9.000		25	+7.000		43	-15.000	
8	- 7.000		26	+9.000		44	-11.000	
9	- 5.000		27	+11.000		45	-9.000	
10	- 1.000		28	+13.000		46	-7.000	
11	+ 1.000		29	-17.000	+10.000	47	-3.000	
12	+ 9.000		30	-15.000		48	-1.000	
13	+11.000		31	-11.000		49	+1.000	
14	-15.000	+11.500	32	- 7.000	+11.000	50	+3.000	
15	-13.000	+12.000	33	- 5.000	+10.000	51	+5.000	
16	-11.000		34	- 3.000		52	+7.000	
17	- 9.000		35	- 1 000		53	+9.000	
18	- 7.000		36	+ 1.000		54	+13.000	

TABLE 3 (cont.)

INSTRUMENTATION LOCATIONS FOR TURNTABLE SKIN

THERMOCOUPLES

T. C. No.	X	Y	T. C. No.	X	Y	T. C. No.	X	Y
55	-9.000	+6.000	89	-7.000	+2.000	123	-3.000	-10.000
56	-7.000		90	-5.000		124	-1.000	
57	-5.000		91	-3.000		125	+1.000	
58	-3.000		92	-1.000		126	-15.000	-11.500
59	-1.000		93	+1.000		127	-13.000	-11.000
60	+1.000		94	+11.000		128	-11.000	-12.000
61	+3.000		95	+13.000		129	-9.000	
62	+5.000		96	+15.000		130	-7.000	-11.000
63	+7.000		97	+19.000		131	-7.000	-12.000
64	+9.000		98	-1.000	+1.000	132	-3.000	
65	+13.000		99	-13.000		133	-1.000	
66	+15.000		100	-11.000		134	+1.000	
67	-11.000	+4.000	101	-9.000		135	+3.000	
68	-9.000		102	-7.000		136	-12.500	-14.000
69	-7.000		103	-5.000		137	-11.000	
70	-5.000		104	-3.000		138	-9.000	
71	-3.000		105	-1.000		139	-7.000	
72	-1.000		106	+11.000		140	-3.000	
73	+1.000		107	+13.000		141	-1.000	
74	+3.000		108	+15.000		142	+1.000	
75	+5.000		109	+17.000		143	+5.000	
76	+7.000	+4.500	110	+19.000		144	-12.500	-15.500
77	+9.000	+4.000	111	-17.000	-8.000	145	-11.000	-16.000
78	+11.000		112	-15.000		146	-9.000	
79	+13.000	+4.500	113	-13.000		147	-7.000	-15.250
80	+17.000	+4.000	114	-11.000		148	-5.000	-16.000
81	-8.000	+3.000	115	-3.000		149	-1.000	
82	-4.000		116	-1.000		150	+1.000	
83	-2.000		117	-5.000		151	+3.000	
84	+1.000		118	+13.000		152	+5.000	
85	-13.000	+2.000	119	-17.000	-10.000			
86	-11.000		120	-15.000				
87	-9.000		121	-11.000				
88	-8.000	+1.500	122	-9.000				

TABLE 3 (cont.)

INSTRUMENTATION LOCATIONS FOR TURNTABLE SKIN

PRESSURE TAPS

P. T. No.	X	Y	P. T. No.	X	Y	P. T. No.	X	Y
1	-3.000	+14.000	28	-3.000	-4.000	55	-5.000	-8.000
2	+3.000	↓	29	-1.000	↓	56	+1.000	↓
3	-9.000	+10.000	30	+1.000	↓	57	+3.000	↓
4	-13.000	+ 8.000	31	+3.000	↓	58	+7.000	↓
5	-5.000	↓	32	+5.000	↓	59	+9.000	↓
6	-11.000	↓	33	+7.000	-4.500	60	+11.000	↓
7	+17.000	↓	34	+9.000	-4.000	61	+17.000	↓
8	-19.000	+6.000	35	+11.000	↓	62	-5.000	-10.000
9	-1.000	-1.000	36	+13.000	-4.500	63	+3.000	↓
10	-13.000	-2.000	37	+17.000	-4.000	64	+5.000	↓
11	-11.000	↓	38	-13.000	-6.000	65	+9.000	↓
12	-9.000	↓	39	-11.000	↓	66	+11.000	↓
13	-8.000	-1.500	40	-9.000	↓	67	+15.000	↓
14	-7.000	-2.000	41	-7.000	↓	68	-5.000	-12.000
15	-5.000	↓	42	-5.000	↓	69	+5.000	↓
16	-3.000	↓	43	-3.000	↓	70	+7.000	-11.000
17	-1.000	↓	44	-1.000	↓	71	+9.000	-12.000
18	0	↓	45	+1.000	-5.750	72	+11.000	↓
19	+11.000	↓	46	+3.000	-6.000	73	+13.000	↓
20	+13.000	↓	47	+5.000	↓	74	+3.000	-14.000
21	+15.000	↓	48	+7.000	↓	75	+7.000	↓
22	+19.000	↓	49	+9.000	↓	76	+9.000	↓
23	-13.000	-4.500	50	+11.000	↓	77	-3.000	-16.000
24	-11.000	-4.000	51	+13.000	↓	78		
25	-9.000	↓	52	+15.000	↓	79		
26	-7.000	-4.500	53	-9.000	-8.000	80		
27	-5.000	-4.000	54	-7.000	↓	81		

TABLE 4

INSTRUMENTATION LOCATIONS FOR AFT FLOOR SKIN

THERMOCOUPLES

T. C. No.	X	Y	T. C. No.	X	Y
1	28.000	+14.000	13	44.000	+2.000
2	36.000	↓	14	24.000	0.000
3	44.000	↓	15	26.000	↓
4	21.000	+ 6.000	16	28.000	↓
5	28.000	↓	17	30.000	↓
6	36.000	↓	18	32.000	↓
7	44.000	↓	19	34.000	↓
8	24.000	+ 2.000	20	36.000	↓
9	28.000	↓	21	38.000	↓
10	32.000	↓	22	40.000	↓
11	36.000	↓	23	42.000	↓
12	40.000	↓	24	44.000	↓

PRESSURE TAPS

P. T. No.	X	Y	P. T. No.	X	Y
1	24.000	-2.000	8	28.000	-6.000
2	28.000	↓	9	36.000	↓
3	32.000	↓	10	44.000	↓
4	36.000	↓	11	28.000	-14.000
5	40.000	↓	12	36.000	↓
6	44.000	↓	13	44.000	↓
7	21.000	-6.000			

TABLE 4 (cont.)

INSTRUMENTATION LOCATIONS FOR AFT SKIN

NOMINAL DIMENSIONS

Runs 75-153

THERMOCOUPLES

T. C. No.	X	Y	T. C. No.	X	Y
1	28.000	14.000	13	44.000	2.000
2	36.000				
3	44.000		15	26.000	0.000
4	21.000	5.000	16	28.000	
5	28.000	6.000	17	30.000	
6	36.000		18	32.000	
7	44.000		19	34.000	
8	26.000	2.000	20	36.000	
9	28.000		21	38.000	
10	32.000		22	40.000	
11	36.000		23	42.000	
12	40.000		24	44.000	

PRESSURE TAPS

P. T. No.	X	Y	P. T. No.	X	Y
1	26.000	-2.000	8	28.000	-6.000
2	28.000		9	36.000	
3	32.000		10	44.000	
4	36.000		11	28.000	-14.000
5	40.000		12	36.000	
6	44.000		13	44.000	
7	21.000	-6.000			

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TABLE 5

SCANIVALVE HOOK-UP SHEET

FLAT PLATE

SETUP #1

AMPL NO / BLK NO	TRANSD NO / RANGE	REF PRES / BAL PRES	RACK NO / MOD LETTER	COMP	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	10		1 A		VAC	FS 1	AS 6	PR 1	TS 22	TS 57	TS 66	TS 72	FS 4	TS 16	PR 2	TS 34	TS 42	TS 49										
	10		1 B		VAC	FS 2	AS 7	TS 2	PR 3	TS 58	TS 67	TS 13	FS 5	TS 17	TS 27	PR 4	TS 43	TS 50										
	0		1 C		VAC	FS 3	AS 8	TS 3	PR 5	TS 59	TS 68	TS 74	TS 9	TS 18	TS 28	TS 35	PR 6	TS 51										
	10		1 D		VAC	FS 6	AS 9	TS 4	TS 37	TS 60	PR 7	TS 75	TS 10	TS 19	TS 29	TS 36	TS 44	PR 8										
	10		1 E		VAC	AS 1	AS 10	TS 5	TS 52	TS 61	TS 69	PR 9	TS 11	TS 20	TS 30	TS 38	TS 45	PR 10										
	10		2 A		VAC	AS 2	AS 11	TS 6	TS 53	TS 62	TS 70	PR 11	TS 12	TS 23	TS 31	TS 39	TS 46	PR 12										
	10		2 B		VAC	AS 3	AS 12	TS 7	TS 54	TS 63	TS 71	PR 13	TS 13	TS 24	TS 32	TS 40	PR 14											
	10		2 C		VAC	AS 4	AS 13	TS 8	TS 55	TS 64	PR 15	TS 76	TS 14	TS 25	TS 33	PR 16	TS 47											
	10		2 D		VAC	AS 5	TS 1	TS 21	TS 56	TS 65	PR 17	TS 77	TS 15	TS 26	PR 18	TS 41	TS 48											
	15		2 E																									

FORM *A270-Q-110 (10-67)

TABLE 5 - CONT'D.

SCANIVALVE HOOK-UP SHEET

THRUSTOR
SETUP #2

AMPL NO. / MUX NO.	TRANSD NO. / RANGE	REF PRES / BAL PRES	RACK NO. / MOD LETTER	COMP	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	10		1 A																T 30	T 41								
	10		1 B																T 32	T 43								
	0		1 C																T 33	T 44								
	10		1 D					SAME AS											T 34	T 45								
	.0		1 E																T 35	T 46								
								SETUP #1																				
	10		2 A																T 37	T 47								
	0		2 B															T 27	T 38	T 48								
	.0		2 C															T 28	T 39	T 49								
	0		2 D															T 29	T 40	T 50								
	.5		2 E		ATM	T 31	T 36	T 42	T 51	T 52	T 53	T 54	T 55	T 56	T 57	PR 19	PR 20											

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TABLE 5 - CONT'D.

SCANIVALVE HOOK-UP SHEET

EQUIPMENT FAIRING

AMPL NO / BLK NO	TRANSD NO / RANGE	REF PRES / BAL PRES	RACK NO / MOD LETTER	COMP	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	10		1 A										A 1	A 10														
	10		1 B										A 2	A 11														
	0		1 C										A 3	A 12														
	10		1 D					SAME AS					A 4	A 13														
	10		1 E										A 5	A 17														
								SETUP # 1																				
	10		2 A										A 6	A 18														
	10		2 B										A 7	A 19														
	.0		2 C										A 8	A 20														
	.0		2 D										A 9	A 21														
	15		2 E		ATM	A 14	A 15	A 16	A 22	A 23	A 24	PR 19																

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TABLE 5- CONT'D

SCANIVALVE HOOK-UP SHEET

THRUSTOR-VVSA COMBINATION

AMPL NO / AUX NO	TRANSD NO / RANGE	REF PRES / BAL PRES	RACK NO / MOD LETTER	COMP	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	10		1 A																		T 1	T 14	T 25					
	10		1 B																		T 2	T 17	T 26					
	10		1 C																		T 3	T 18						
	10		1 D					SAME				AS									T 4	T 19						
	10		1 E																		T 5	T 20						
								SETUP				#2																
	10		2 A																		T 6	T 21						
	10		2 B																		T 9	T 22						
	10		2 C																		T 10	T 23						
	0		2 D																		T 13	T 24						
	.5		2 E																T 7	T 8	T 11	T 12	T 15	T 16					

TABLE 6

DESCRIPTION OF SELECTED SYMBOLS ON

REDUCED BOUNDARY LAYER DATA

(Phase I)

SYMBOL	DESCRIPTION	UNITS
RUN	Refers to run number	--
DEL P	P Plenum minus P/N/21	psi
PREF	Scanivalve check pressure; tabulated data incorrect; subtract atmospheric pressure for correct reading	psia
PW/PR	Local static wall pressure/rake pitot pressure	dimensionless
MR	Mach number computed using PW/PR	dimensionless
MR/ME	MR/M_∞	dimensionless
UR/UE	$\frac{MR}{ME}\sqrt{\frac{TR}{TE}}$	dimensionless
DELSTAR	$1 - \frac{TE}{TR} \cdot \frac{UR}{UE}$	dimensionless
THETA	$\frac{TE}{TR} \cdot \frac{UR}{UE} \left(1 - \frac{UR}{UE}\right)$	dimensionless
T/TE	TR/TE	dimensionless
Δ(U/UE)	Difference between a calculated and a measured velocity ratio	dimensionless
ME	Freestream Mach number	dimensionless
PTE, PTE/PT, FZT, FC, FRTHETA	Data not applicable	--
N	$N \approx (y/\delta)^{1/n}$	--
DELTA	A calculated boundary layer thickness	in
TE	Static temperature at edge of boundary layer	^oR
TR	Static temperature at an orifice on the rake	^oR
UR	Velocity at an orifice on the rake	ft/sec
UE	Velocity at the edge of the boundary layer	ft/sec
DATE	Date of data reduction	--

TABLE 6 (cont.)

DESCRIPTION OF SELECTED SYMBOLS ON

REDUCED HEAT TRANSFER AND PRESSURE DATA

(Phases II and III)

FREESTREAM PARAMETERS

SYMBOL	DESCRIPTION	UNITS
MACH	Mach No. from tunnel calibration	dimensionless
PT	Freestream total pressure	psia
PS(PSIA)	Freestream static pressure	psia
Q(PSI)	Freestream dynamic pressure	psia
TT(R)	Freestream total temperature	^{o}R
RE/IN/M	Unit Reynolds No. x 10^{-6}	in^{-1}
DP1, DP2 DP3, DP4	Differential pressures across floorplate	psid
PSW	Tunnel sidewall static pressure	psia
PTJ	Ejector total pressure	psia
RHOT	Freestream total density	$slugs/ft^3$
RINF	Freestream static density	$slugs/ft^3$
UINF	Freestream velocity	fps
TINF	Freestream static temperature	^{o}R
PN21	Static pressure at nozzle exit	psia
MSW	Freestream Mach No. computed from PT and PSW	dimensionless
DATE	Date of data reduction	----

HEAT TRANSFER DATA

SYMBOL	DESCRIPTION	UNITS
HO	Average heat transfer coefficient from flat plate reference runs	Btu/ft^2-sec°-F
ID*	Model thermocouple identifier	--
T(R)	Model thermocouple temperature	^{o}R
SLOPE	dT/dt calculated at the midpoint of a quadratic determined from 11 or 21 consecutive measurements	^{o}F/sec
Q	Local heating rate	Btu/ft^2-sec

TABLE 6 (cont.)

HEAT TRANSFER DATA

SYMBOL	DESCRIPTION	UNIT
H	Local heat transfer coefficient calculated from model thermocouple data	Btu/ft^2-sec°-F
PREF	Reference pressure read on a transducer removed from scanivalves	psia
PR1, PR2, . . . PR20	PR1/PREF, PR2/PREF, etc.	dimensionless
ID*	Model pressure tap identifier	--
P(PSIA)	Model pressure	psia
P/PS	Model pressure to freestream static pressure ratio	dimensionless
CP	Coefficient of pressure	dimensionless

* Model thermocouple and pressure tap ID number prefixes are defined as follows:

FS	Forward skin
TS	Turntable skin
AS	Aft skin
T	Thrustor and VVSA models
A	Equipment fairing model

Figure 1. Turntable Base and Floor Skin Cooling System.

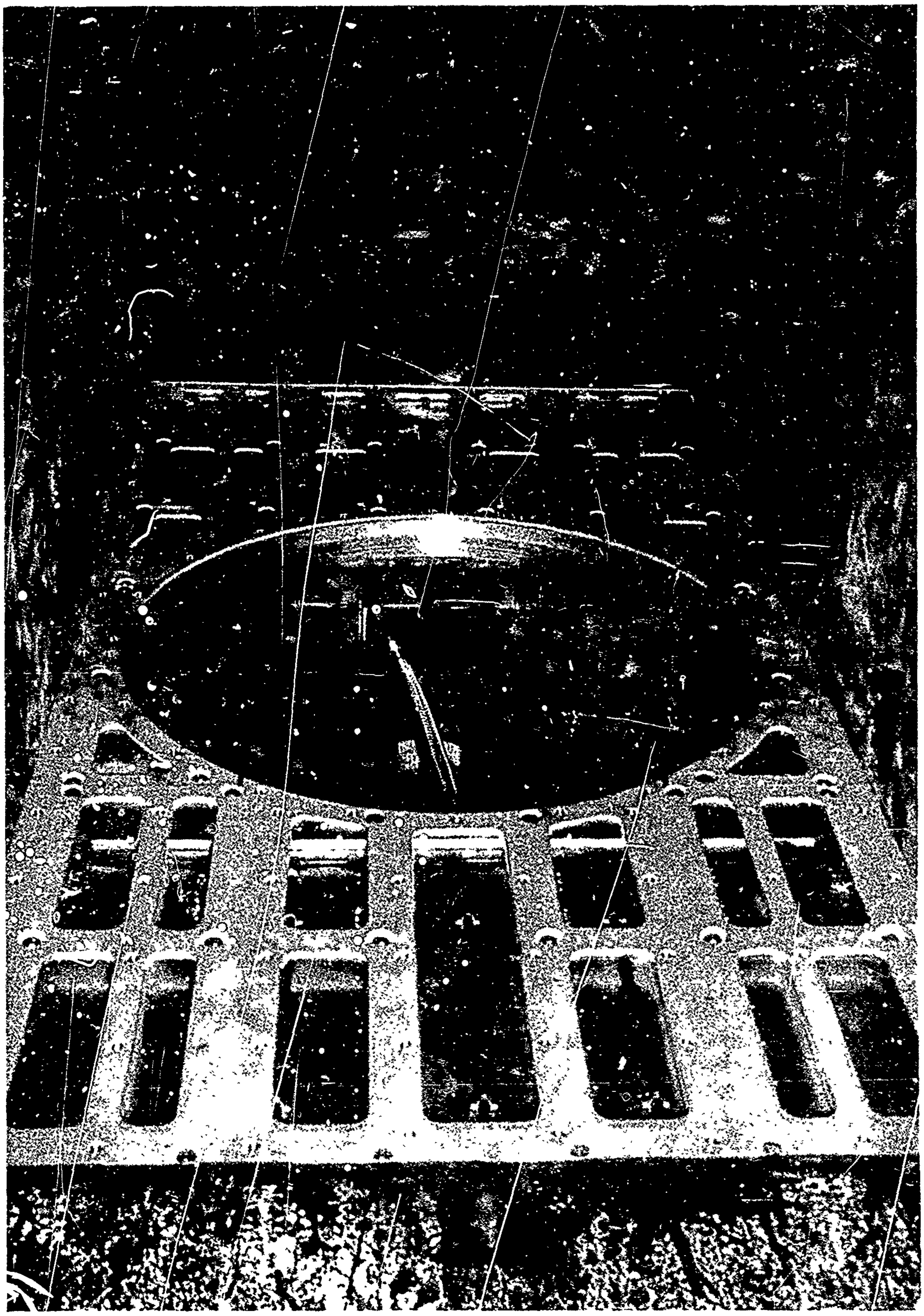


Figure 2. Floor Skin Insulation

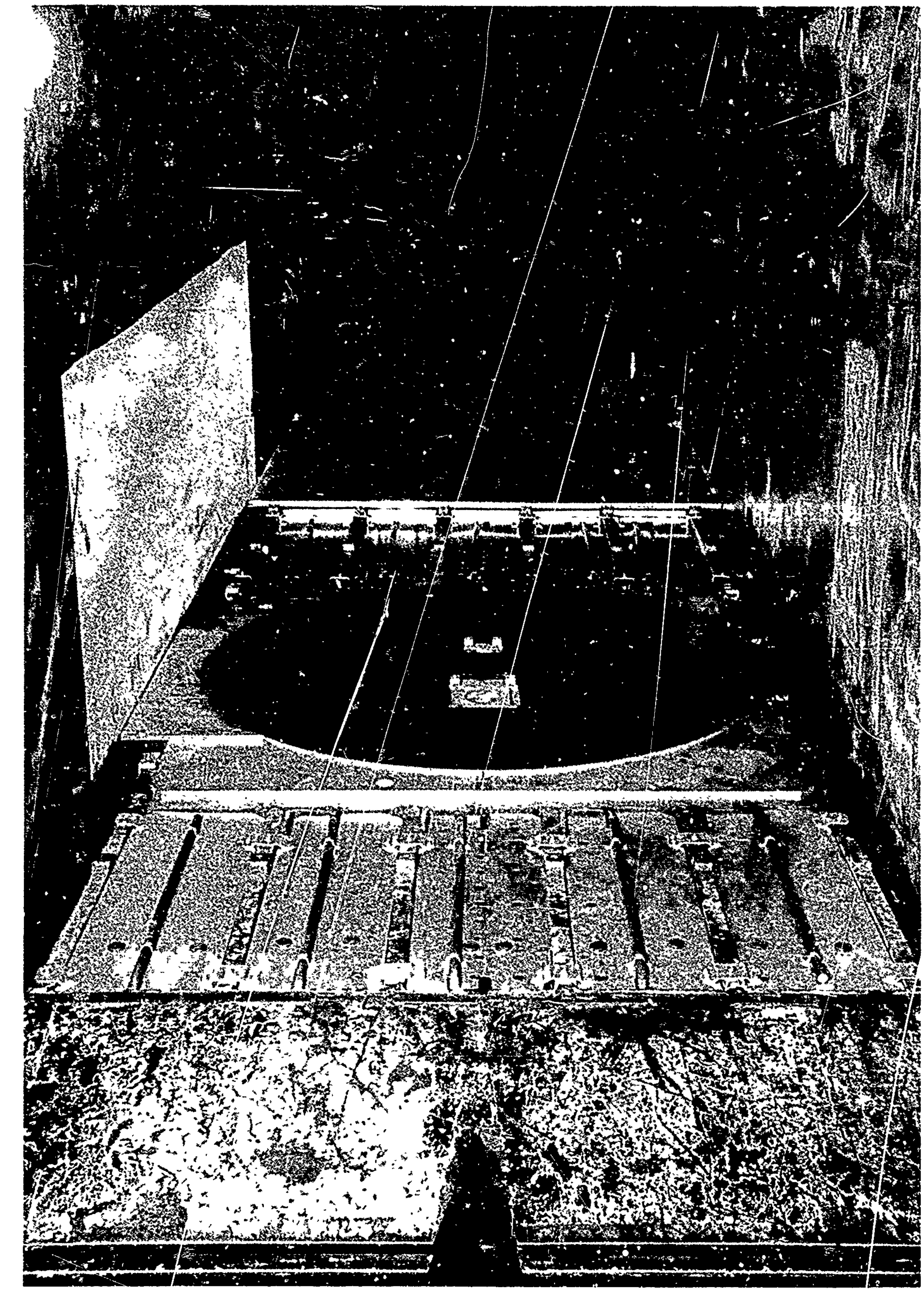


Figure 3 Turntable Installation

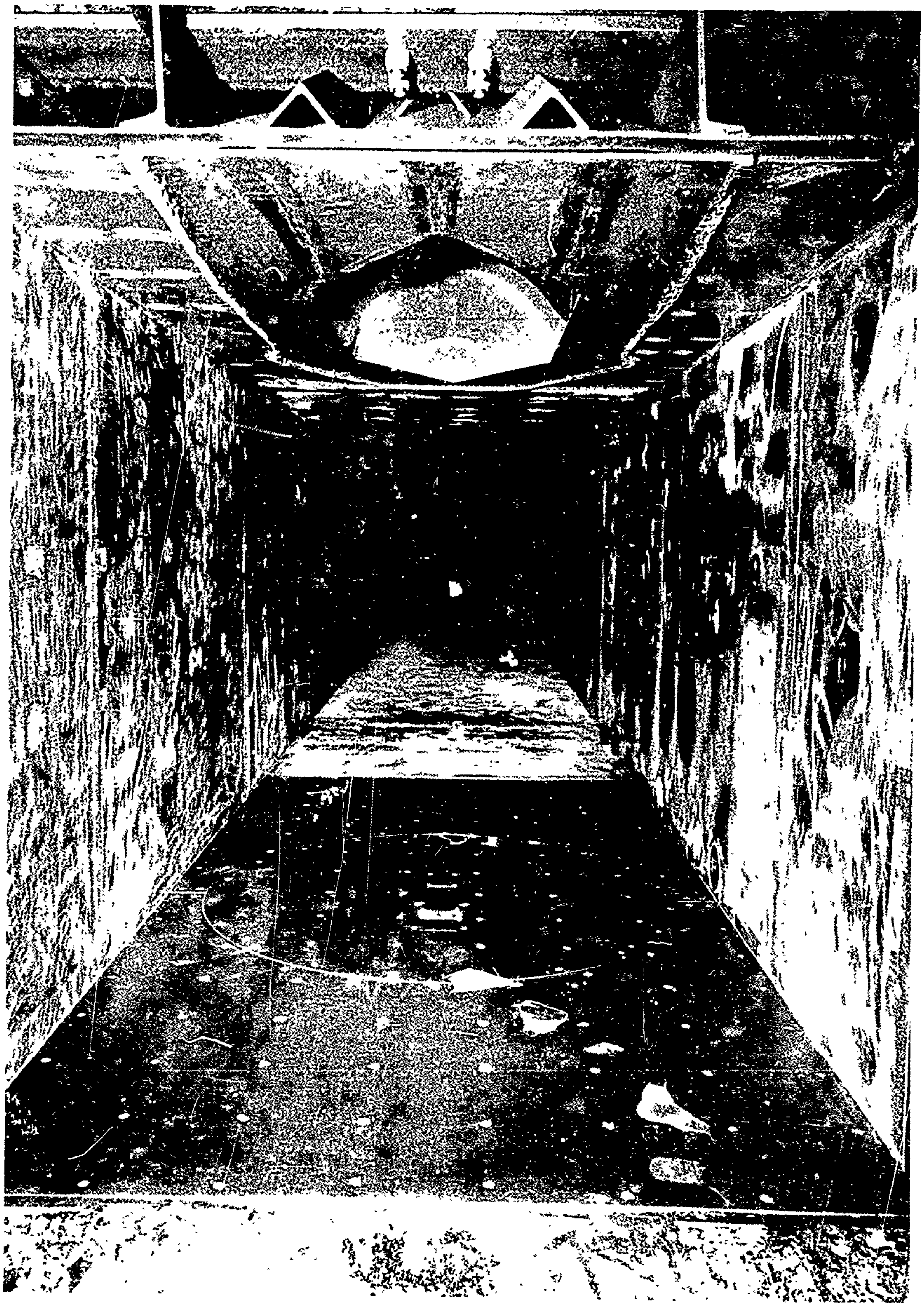


Figure 4. Complete Floor Skin Installation

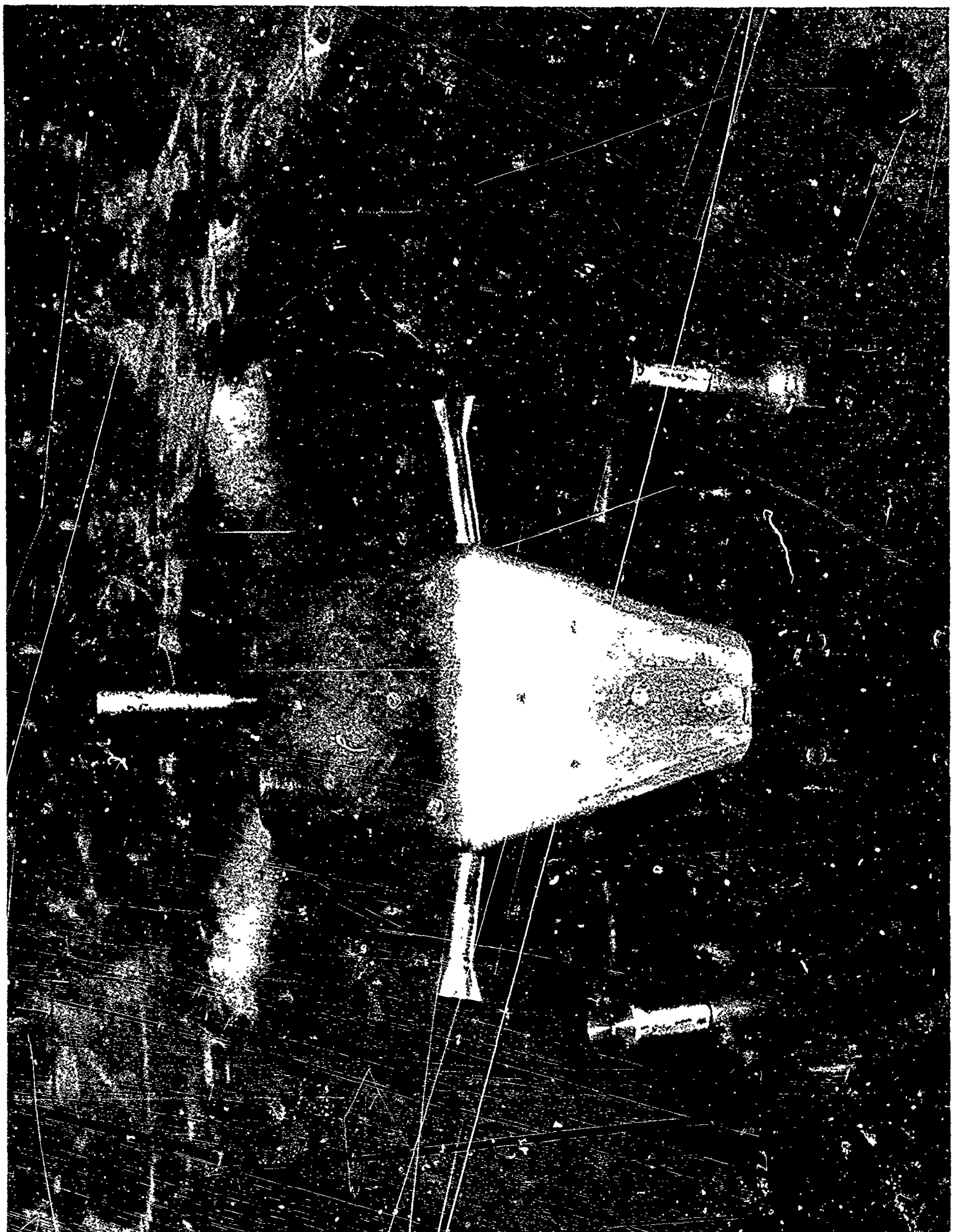


Figure 5. Thrustor Module Assembly Model

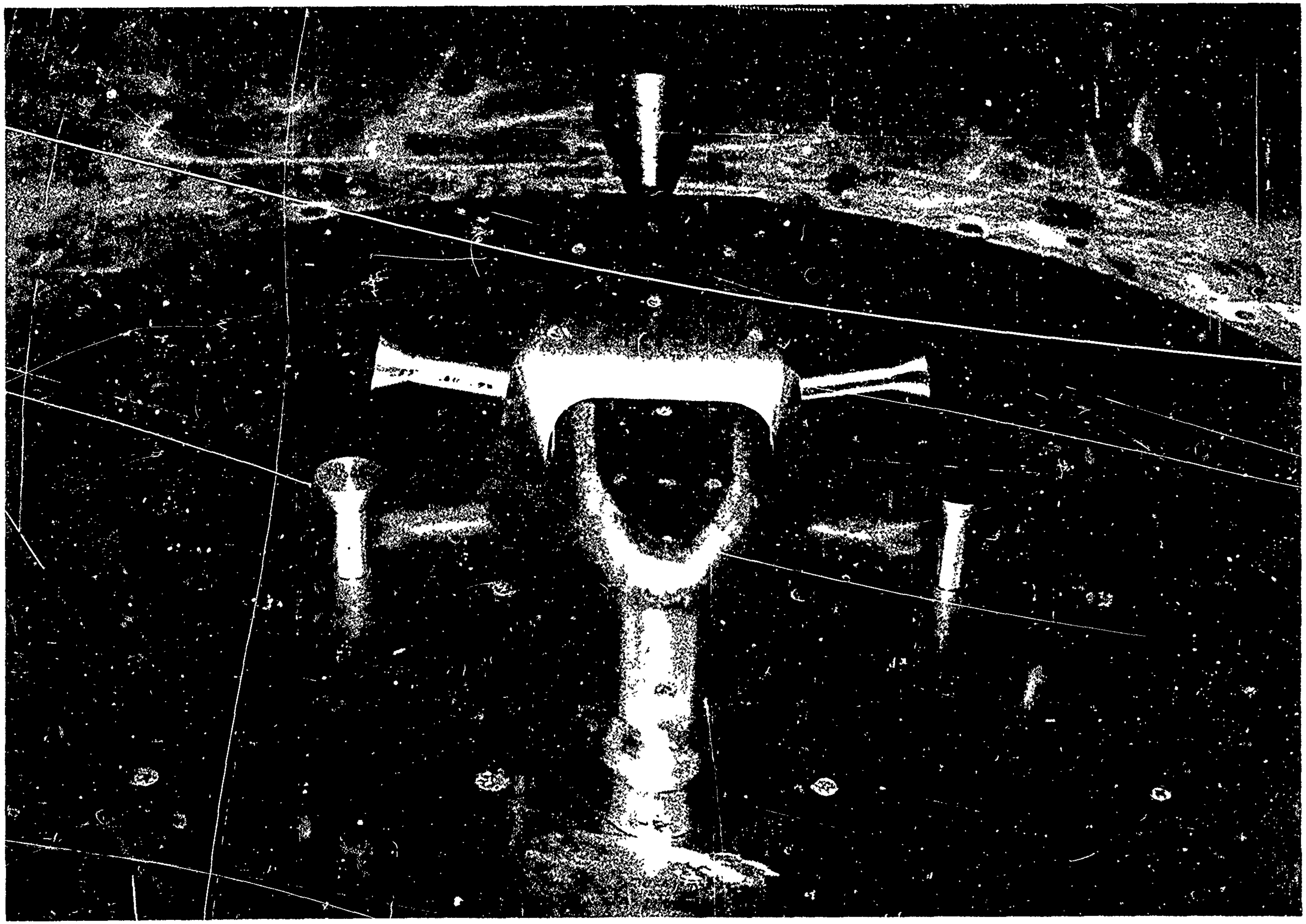
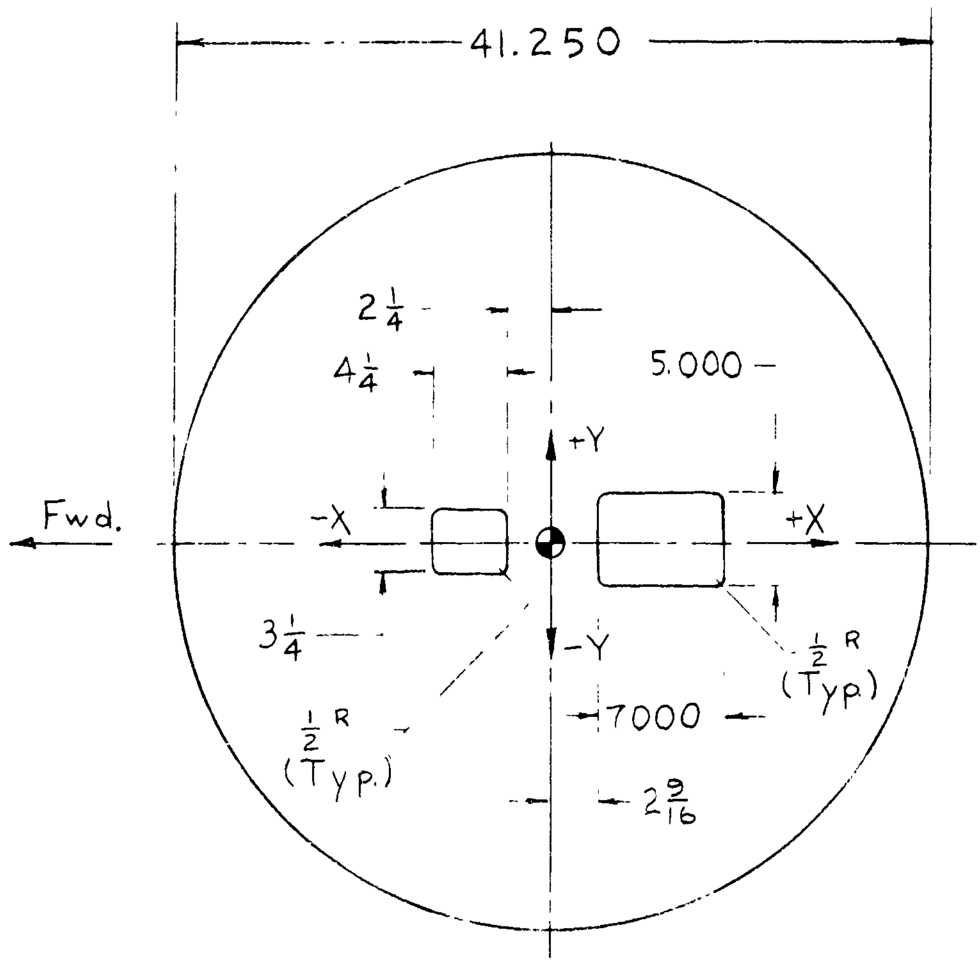


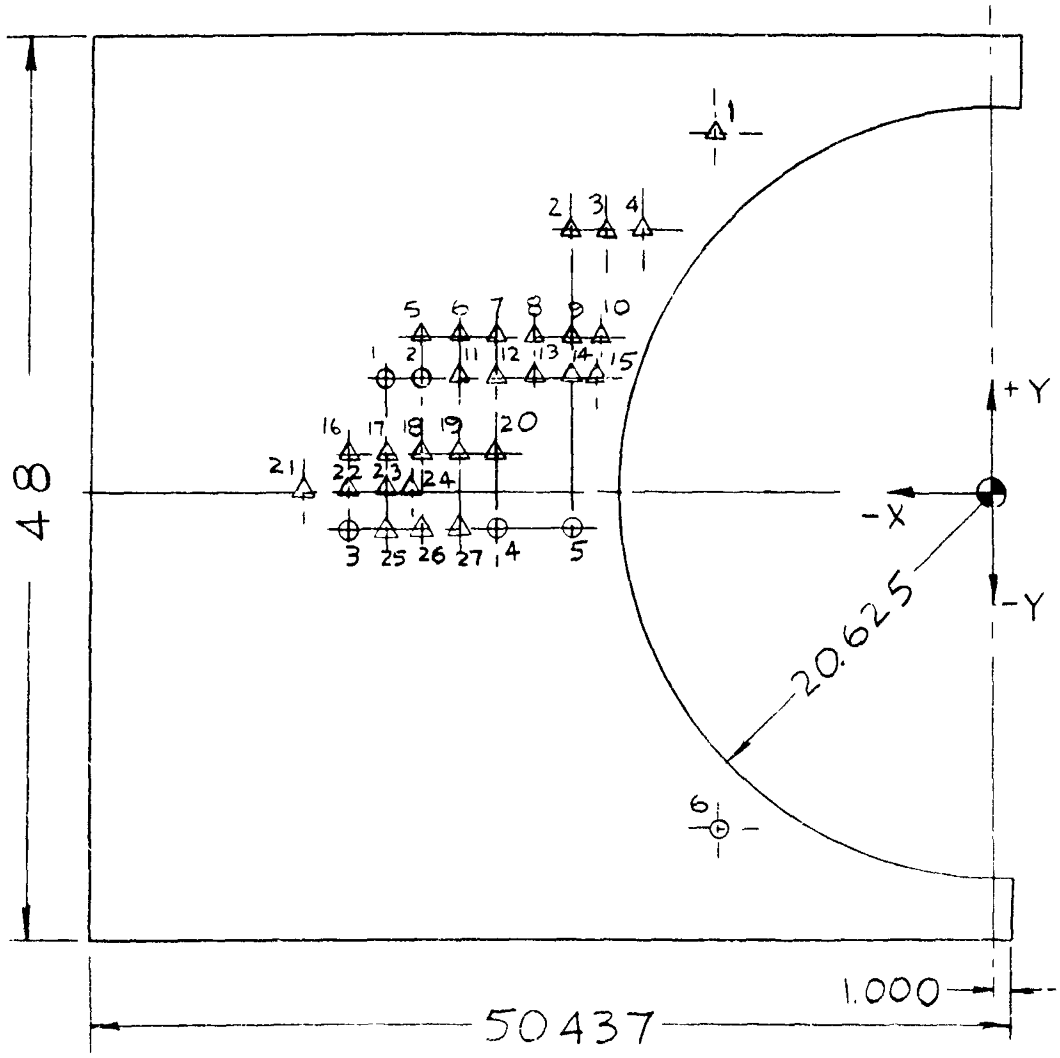
Figure 6. Thrustor Module Assembly and VVSA Fairing Models

Figure 7. Equipment Fairing Model



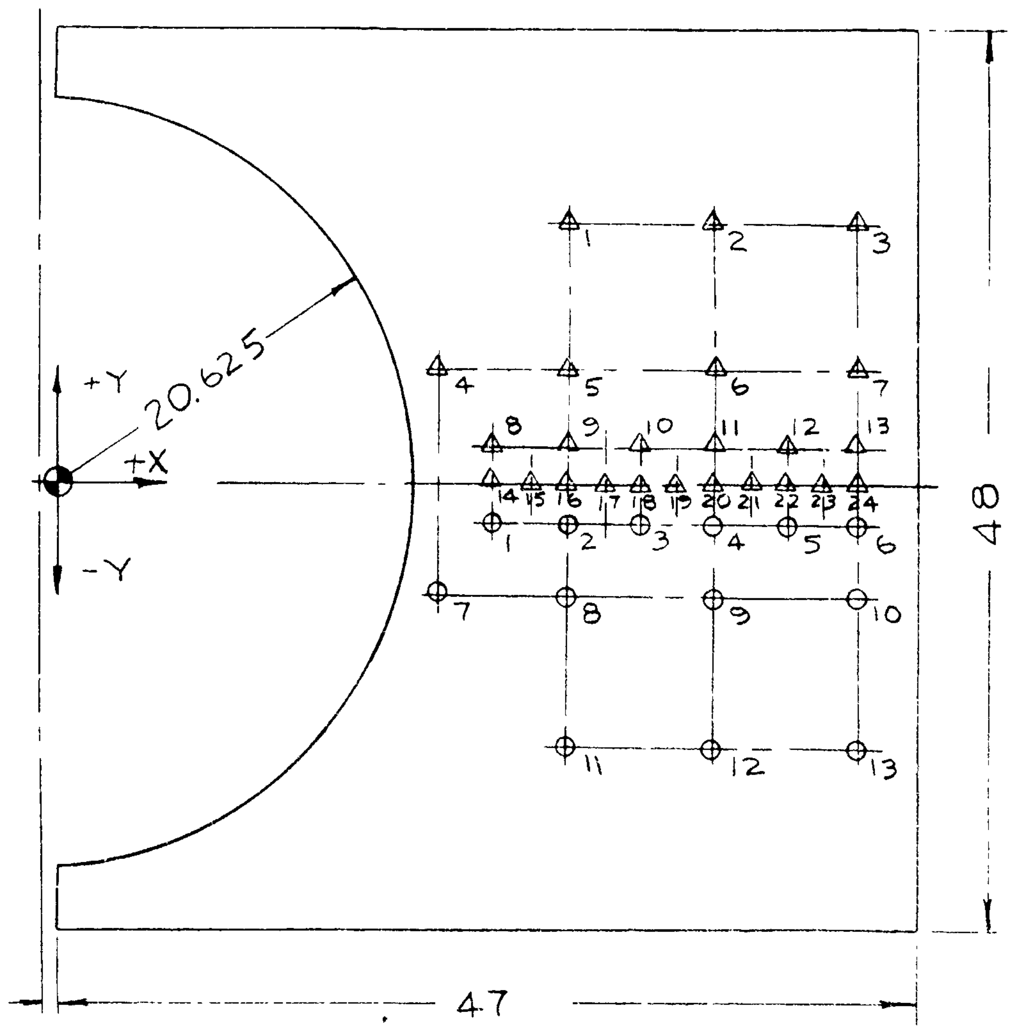
NOTE: Cutouts are for mounting models.
See table 3 for instrumentation locations.

Figure 8. Turntable Skin Dimensions



NOTE: See table 2 for instrumentation locations

Figure 9. Forward Floor Skin Dimensions



NOTE: See table 4 for instrumentation locations

Figure 10. Aft Floor Skin Dimensions

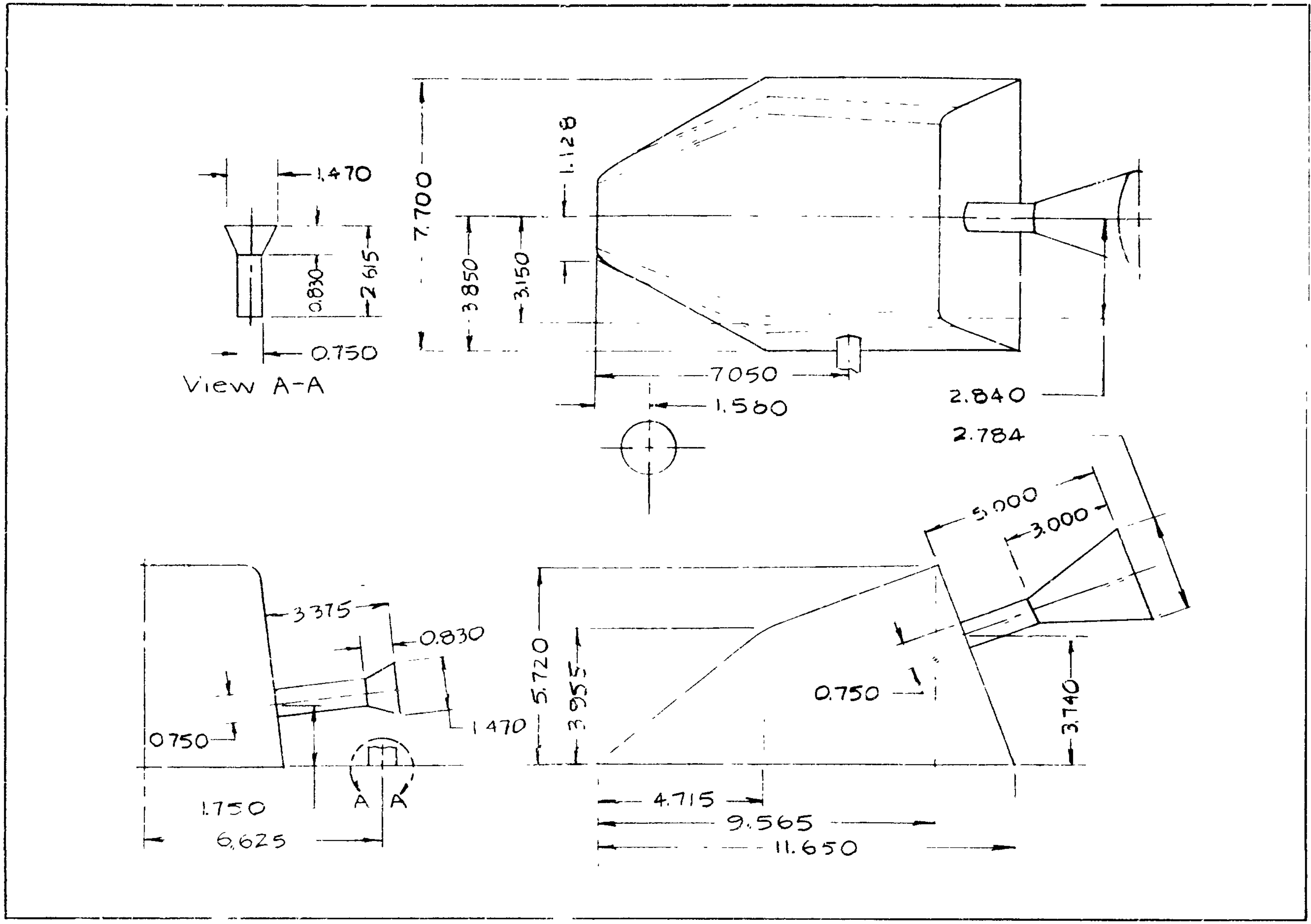


Figure 11. Thrustor Module Assembly Model Dimensions

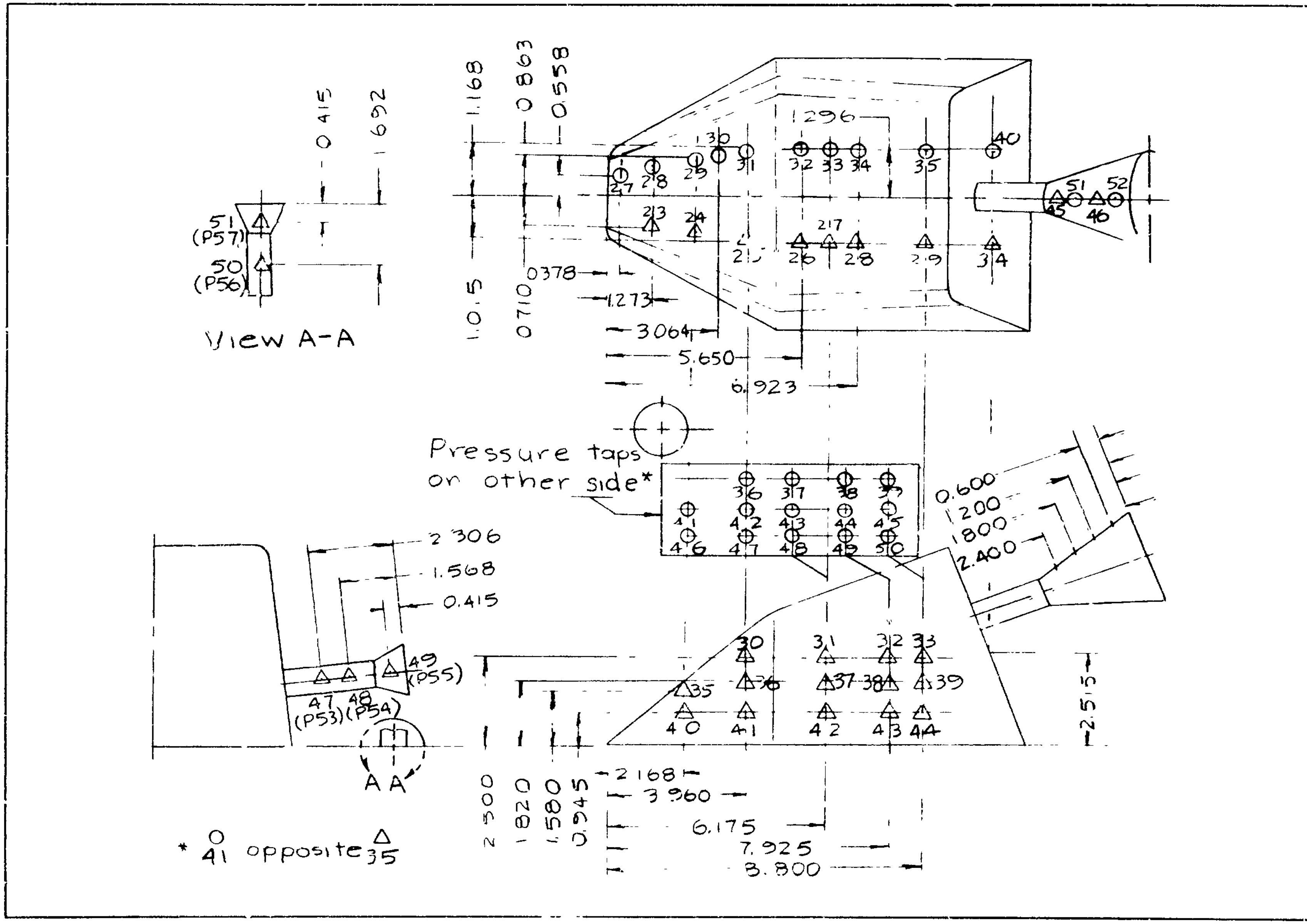


Figure 12. Thrustor Mod..le Assembly Model Instrumentation Locations

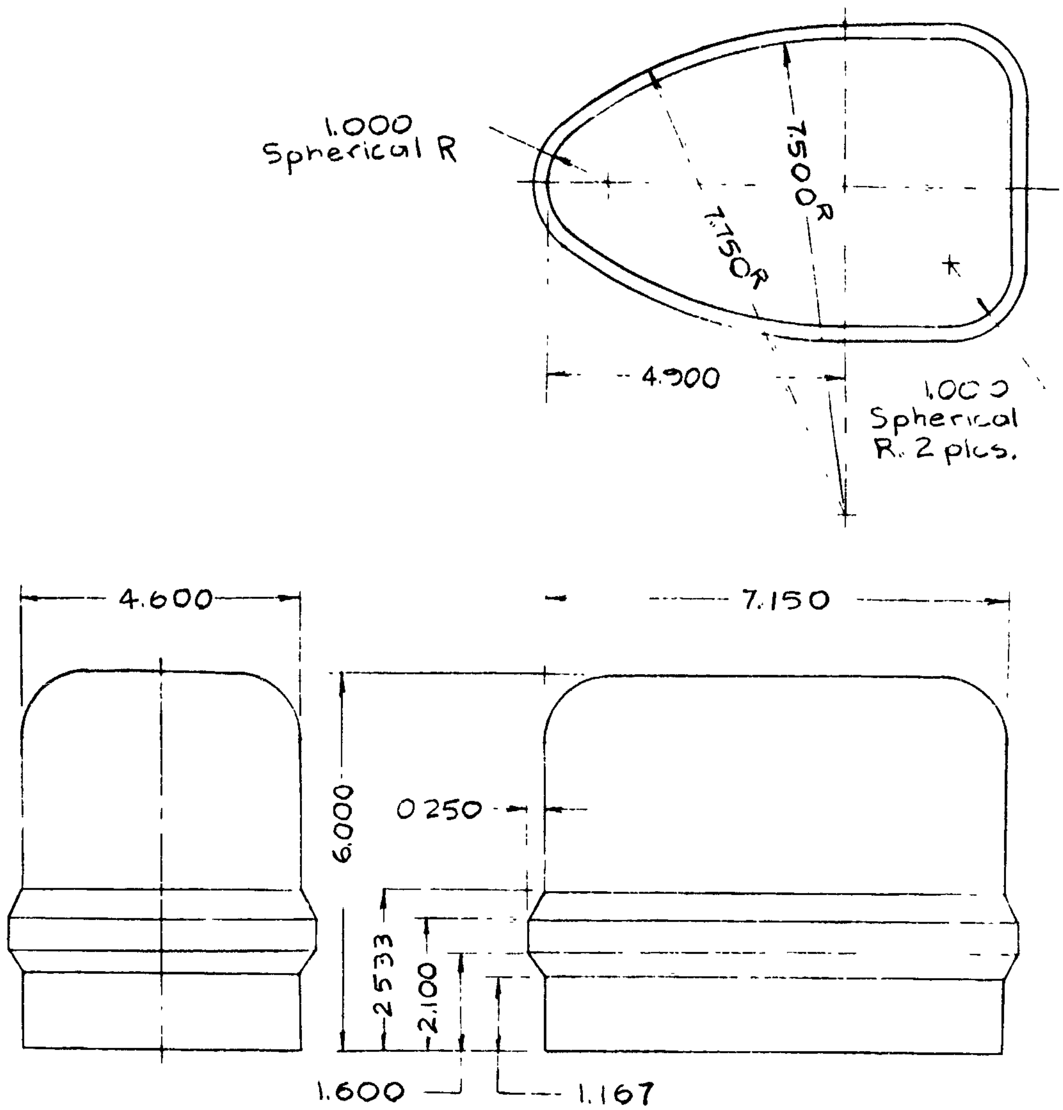


Figure 13. VVSA Fairing Model Dimensions

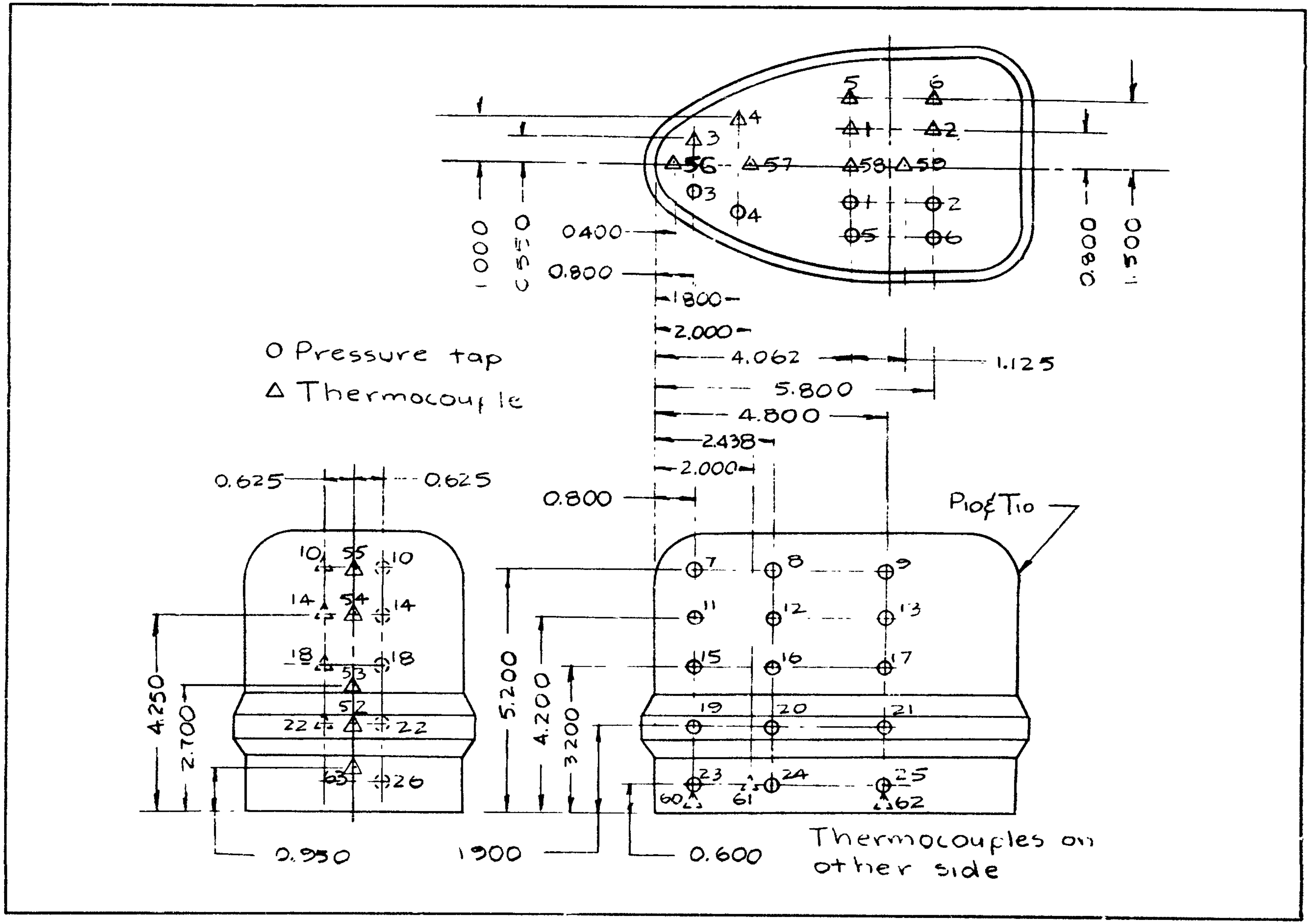


Figure 14. VVSA Fairing Model Instrumentation Locations

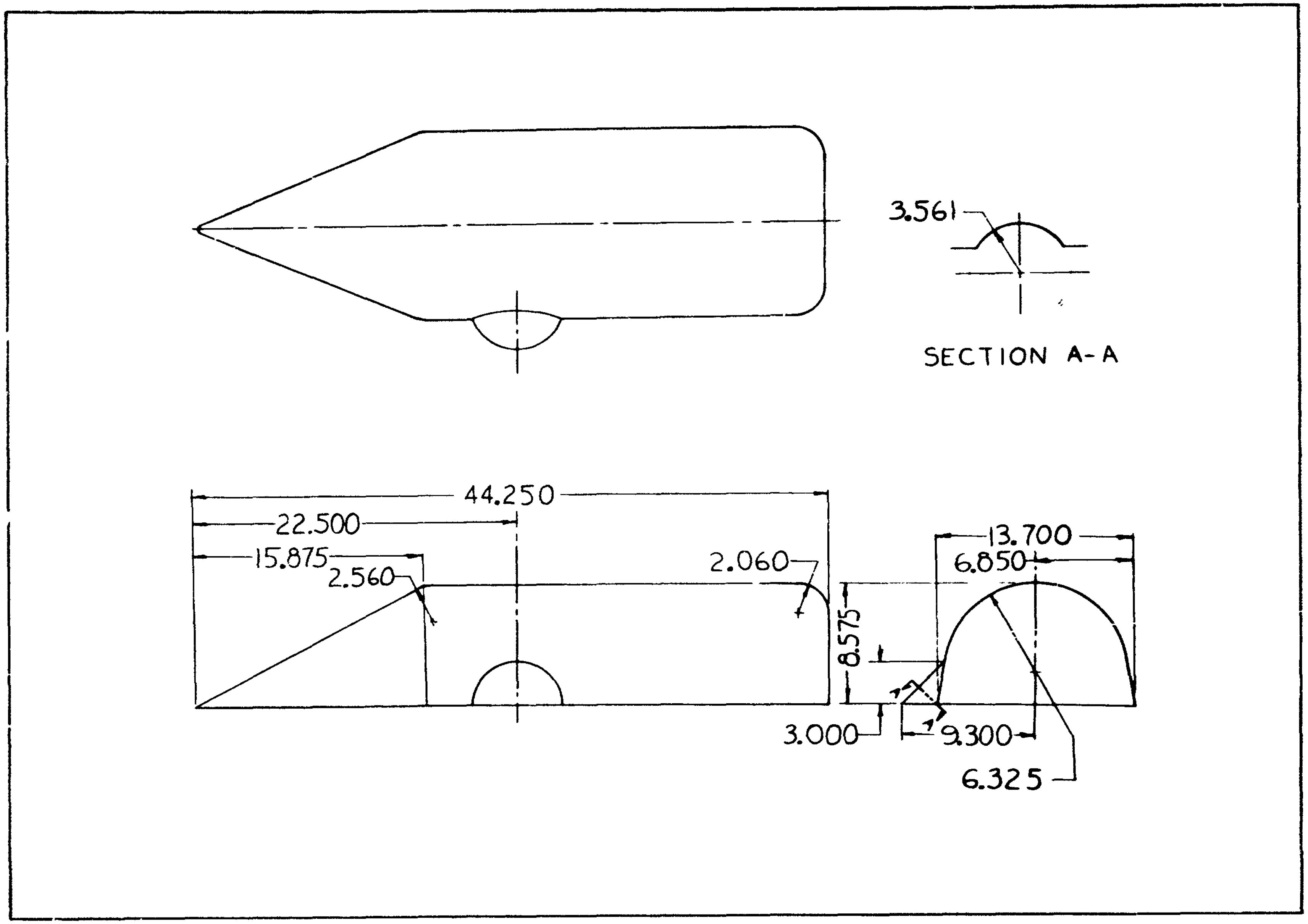


Figure 15. Equipment Fairing Model Dimensions

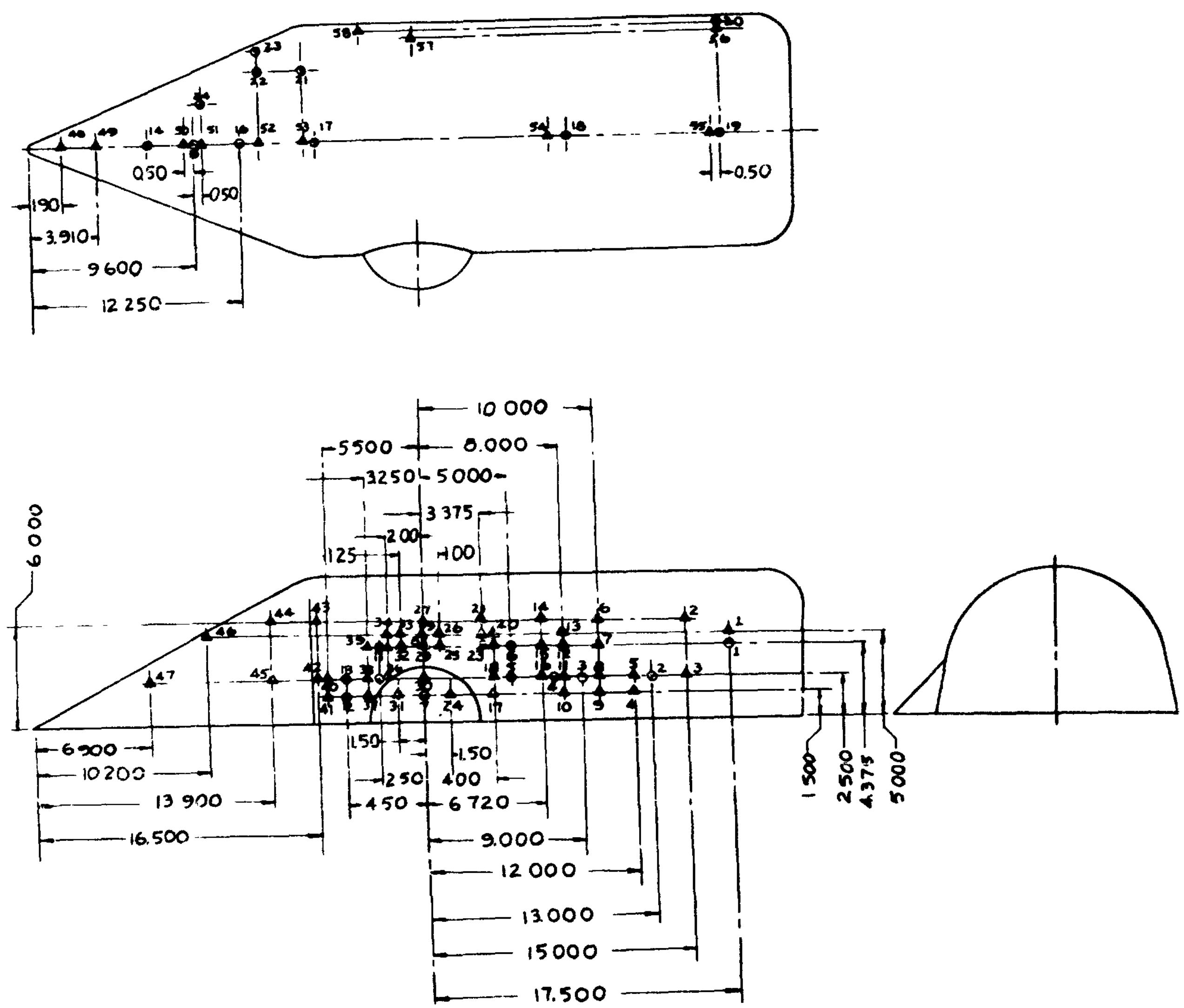


Figure 16. Equipment Fairing Model Instrumentation Locations

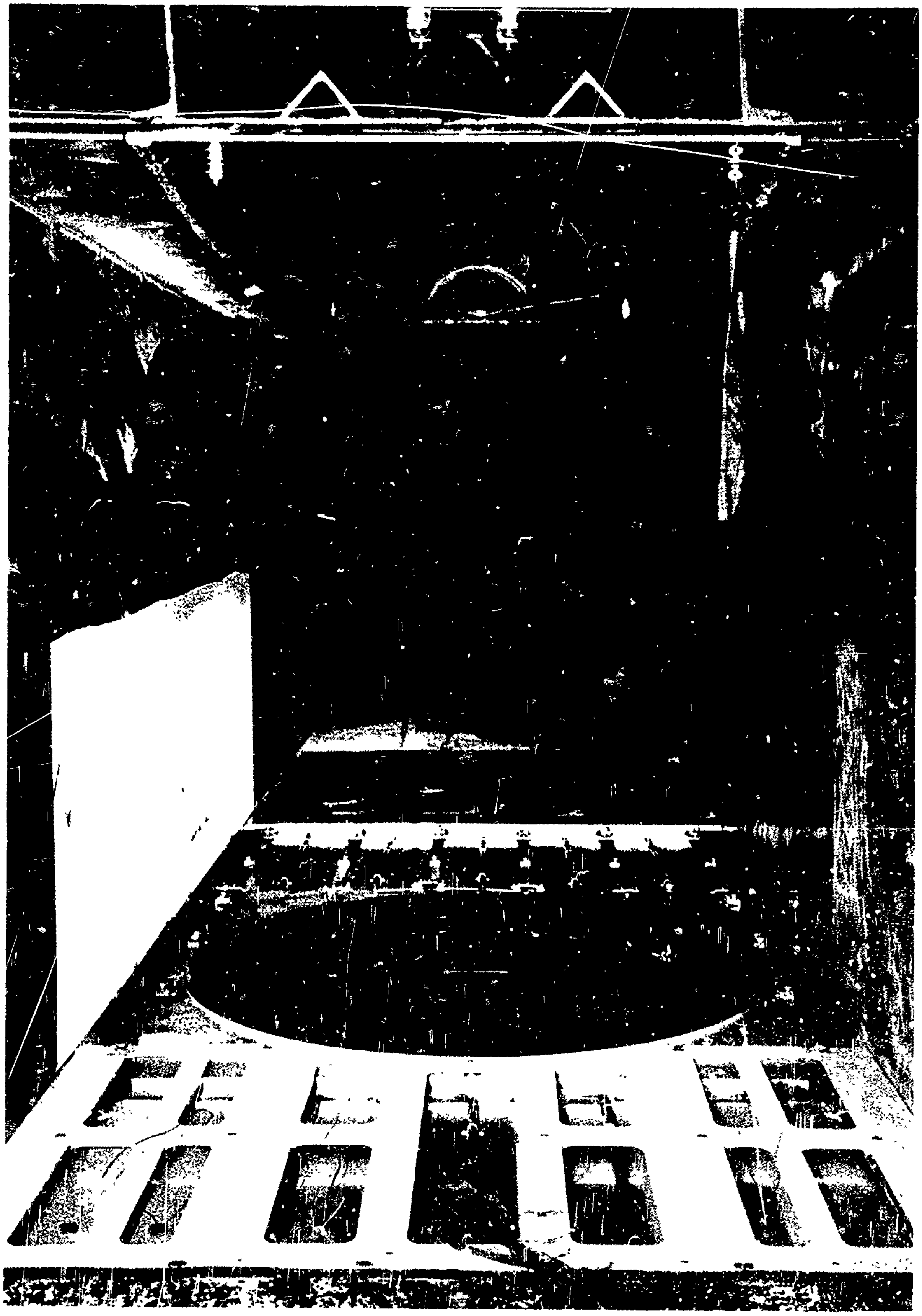


Figure 17. Tunnel Floor After Skin Failure

Figure 18. Failed Skin

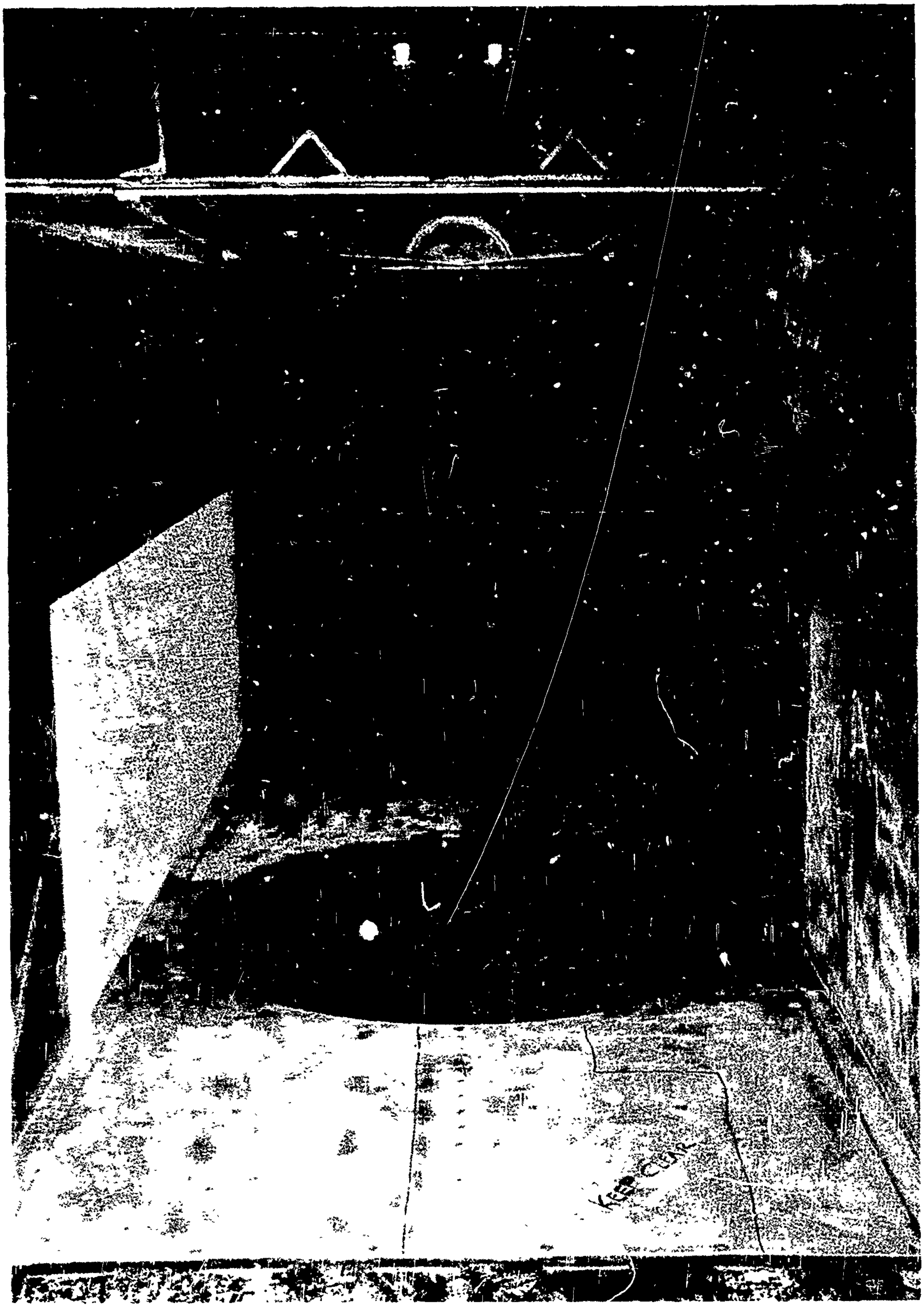


Figure 19 Aluminum Plate Replacement After Failure

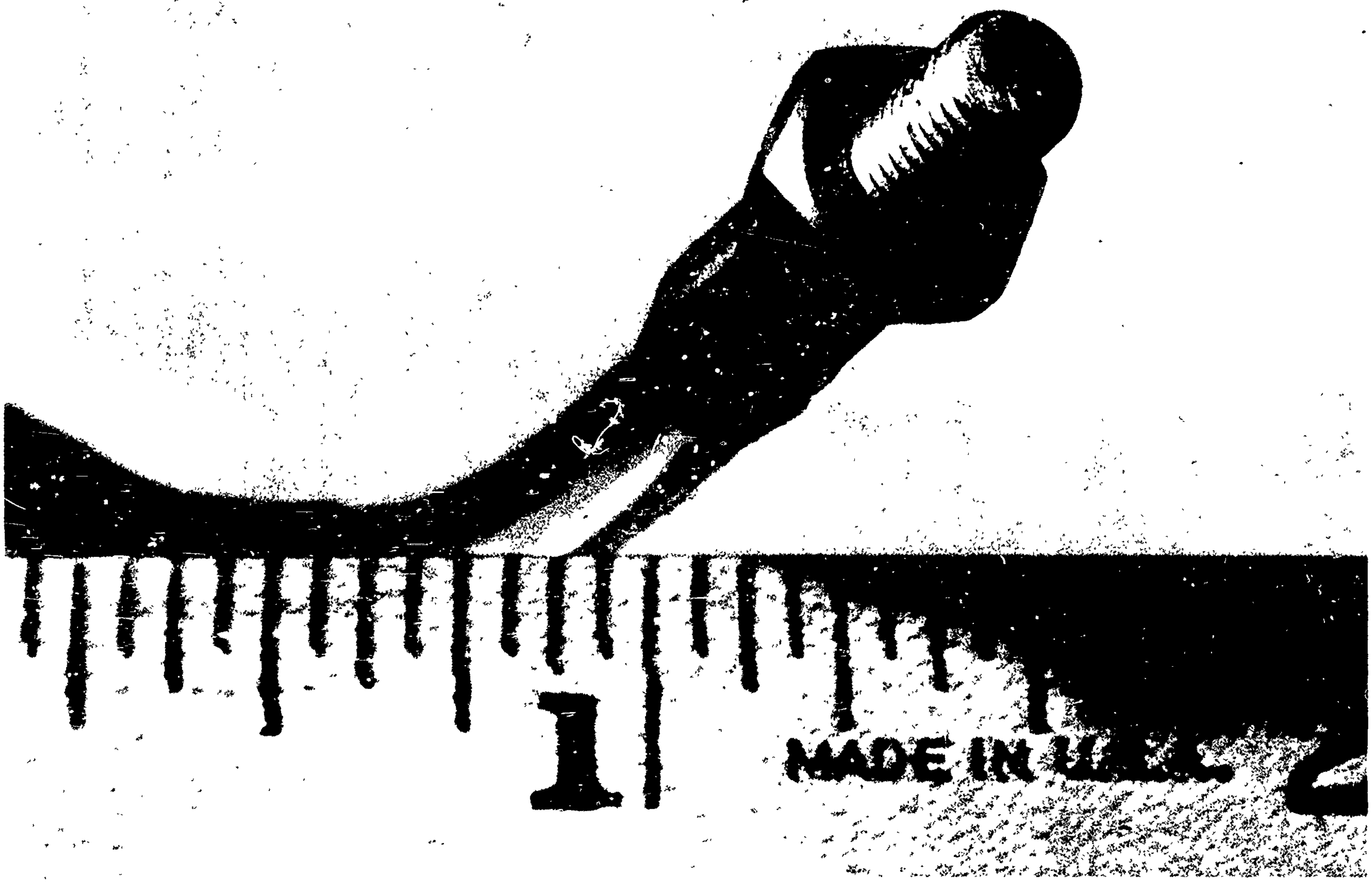


Figure 20. Closeup of NANMAC Gage

5.0 REFERENCES

1. Haldane, G. F., "Fluid Dynamics Test Pretest Report - MOL Protuberance Heating," DAC 58780, dated 26 February 1968

2. SAFSL Exhibit 21010, "Fluid Dynamics Test Requirements Study and Test Plan," dated 1 September 1966, revised May 3, 1967